Proposed Modifications to the Wind Loading Specifications Applied to Ground Antennas

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As the survival wind velocity specification mainly controls the final weight of the reflector structure of a ground antenna, this reporting of a study of the latest wind data shows that the survival specification can be lowered, and therefore the weight can be lowered, from 53.0 m/s (120 mi/h) to less than 44.1 m/s (100 mi/h). The results are based on analysis methods as recommended by the existing design guides. However, the next study reporting will be based on considerations of the dynamic action of wind, which is the upgraded analysis method described in the literature.

I. Introduction

During the design period of the 64-m antenna, the two specifications that controlled the minimum weight of the antenna structure were (1) the requirement to satisfy the minimum natural frequency of vibration of 1.5 Hz, which mainly affected the weight of the alidade and the elevation wheel assembly of the reflector, and (2) the requirement to survive in a 53.0 m/s (120 mi/h) wind in stow configuration, which controlled the weight of the reflector structure. In the truss type of structure used for antenna assemblies, the weight is closely proportional to the cross-sectional areas of the bar elements of the truss, which directly reflects its stiffness and strength.

This article describes the results of a study made to redefine the survival wind velocity based on recent wind data and the use of the latest engineering methods to resolve the actual wind loadings on the antenna structure by the environmental winds at the Goldstone Deep Space Communications Complex.

This report describes the wind data and calculations for wind loadings based on existing design guides (Refs. 1 and 2) published by the American Society of Civil Engineers. A future report will describe the application of formulations based on statistical concepts of random vibrations pioneered by Davenport (Ref. 3).

II. Discussion

To determine the stow wind pressures on the antenna, it is necessary first to select the design velocity, which is the maximum average wind velocity for a selected time period that is proper for the locality. Gust pressures must be included. Gusts are relatively short-period horizontal and vertical fluctuations of the wind, but are of sufficient extent to envelop the antenna and permit the corresponding aerodynamic effects to develop.

At Goldstone, we can eliminate consideration of tornadoes, hurricanes and icing. The storms which generate the high winds here are described as "extratropical cyclones" (Ref. 2) that cross the United States at a rate of about 2 cyclones per week.

Thom (Ref. 4) of the U.S. Department of Commerce, published results of wind data taken throughout the United States by the U.S. Weather Bureau which were statistically analyzed and resolved in maps showing contours of the annual fastest mile of wind in miles per hour at 30 feet above ground. The 100-yr Probable Period of Recurrence Map is reproduced as Fig. 1. This mile of wind velocity is computed as: Velocity (mph) = 1/Time, in hours, of passage of one mile of wind, and is also the average velocity for the measured time period.

The Task Committee on Wind Forces of the Society of Civil Engineers (ASCE) (Ref. 2) recommends the use of a basic velocity from the 50-yr period of recurrence for all permanent structures except those that, in the judgment of the engineer, have a high degree of wind sensitivity and an unusually high degree of hazard to life and property in case of failure. The ground antenna is judged to be in the latter classification. The wind speeds in Fig. 1 have the probability of being exceeded of 0.01. For the U.S., these speeds are, on the average, 1.08 times the corresponding speeds for the 50-yr winds.

The location of the Goldstone Deep Space Communications Complex is indicated by the X on Fig. 1. The wind velocity is 32.63 m/s (73 mi/h) at 9.14 m (30 ft) height above ground. This recommendation (Ref. 2) is based on conditions in open, level country as a standard of reference also described as exposure "C," and the influence of shielding or of deflections and channelling due to unusual topography or to large obstructions is expected to be separately evaluated. The present Mars 64-m antenna location is judged to be in open country because of the long stretch of smooth terrain approaching the location in the high wind direction. Figure 2 shows a plot of the 1/7 power-law curve common to open country or exposure "C" going through the 15.9-m (52-ft) height measured 5-min average wind speed with the measured simultaneous values for 45.7-m (150 ft) and 87.1-m (286 ft) heights placed on the graph. A good fit of the measured data to the 1/7 power curve results.

In stow configuration the 64-m antenna height is 51.82 m (170 ft). Based on the 1/7 power curve, the 32.63-m/s (73-mi/h) velocity at 9.14 m (30 ft) translated to 40.3-m/s (93.5-mi/h) velocity by Eq. (1) at a height of 51.82 m (170 ft) equals:

$$V_z = V_{9.14}\left(\frac{Z}{V_{9.14}}\right)^{1/m}$$

$$V_{51.82} = 32.63\left(\frac{51.82}{9.14}\right)^{1/7} = 41.8\ \mathrm{m/s}\ (93.5\ \mathrm{mi/h}) \qquad (1)$$

where

V_z = velocity at height Z = 51.82 m

$V_{9.14}$ = basic velocity at 9.14-m (30-ft) height

m = exponent

If we follow the recommendations of the Task Committee on Wind Forces of ASCE (2), a gust factor in terms of a multiplier to the extreme wind speed must be developed.

The Task Committee recommends the use of a curve from (5) which defines the gust factor (gust velocity ÷ 5 min average velocity) in terms of the gust duration. The curve may be expressed by a fitted equation

$$Y = \left(\frac{300}{D}\right)^{0.0399} \qquad (2)$$

Y = gust factor

D = gust duration

The gust duration is the time the basic velocity takes to travel 6 to 8 times the longitudinal length of the object or antenna. This, in fact, defines the "minimum effective gust size" required to envelop and develop the incremental aerodynamic pressures (Ref. 5).

If we use the conservative recommendations in Ref. 6 of 4 times the smallest of the height and the longitudinal length, we have

Wind velocity at 51.82 m = 41.8 m/s

$$\text{Gust duration } D = \frac{4 \times 51.82}{41.8} = 4.96\text{, say 5 sec}$$

Since the gust factors of Ref. 5 are based on the 5-min average wind velocity, a conversion is required from the mile of wind velocity. This may be done by Fig. 3 which is reproduced from Ref. 6 and is based upon the results of a statistical analysis of data obtained in strong winds over flat, unobstructed terrain. Figure 3 shows, for a given period of t seconds used to average a wind speed, the factor F, the ratio of the average probable maximum wind speed to the mean hourly speed.

First, the averaging period t for the fastest mile of wind is from (Ref. 6)

$$t = \frac{3600}{V_f} \text{ s}$$

V_f = the fastest mile velocity in mph

for 41.8 m/s (93.5 mi/h) $t = 3600/93.5 = 38.5$ s

F from Fig. 3 for $t = 38.5 = 1.29$

F from Fig. 3 for $t = 300 = 1.10$
($t = 300$ for 5-min average)

$$\text{5-min average wind speed} = \frac{41.8 \times 1.10}{1.29} = 35.6 \text{ m/s}$$

From Eq. (2)

$$\begin{aligned} \text{Gust factor} &= \left(\frac{300}{D}\right)^{0.0399} \\ &= \left(\frac{300}{5}\right)^{0.0399} \\ &= 1.177 \end{aligned}$$

$$\begin{aligned} \text{Maximum design wind velocity} &= \text{5-min average speed} \times \text{gust factor} \\ &= 35.6 \times 1.177 = 41.9 \text{ m/s (95.1 mi/h)} \end{aligned}$$

which is only 0.1 m/s over the extreme mile of wind speed at a height of 51.82 m (170 ft).

III. Conclusions

The results of this study using the recommendations from the design guides show that the extreme mile of wind speed at the top height of the stowed 64-m antenna represents the maximum design wind velocity, since the effects of gusts are shown to be negligible for the size of the 64-m antenna.

The exposure of the antenna location is based on a terrain classified as flat, open, grassland country. As shown in Fig. 2, the actual measured wind speeds on the 91-m (300-ft) tower near the Mars station at Goldstone show a close fit to the 1/7 power velocity curve of this type of exposure.

The actual measured extreme wind speeds during the period from September 1966 to August 1967 on the tower at the 15.2-m (50-ft) height was in the range of 17.0–18.3 m/s (56–60 mi/h) in January 1967 and at the 45.7-m (150-ft) height was 21.6–22.9 m/s (71–75 mi/h). These wind speeds were lower than that predicted by Fig. 1.

References

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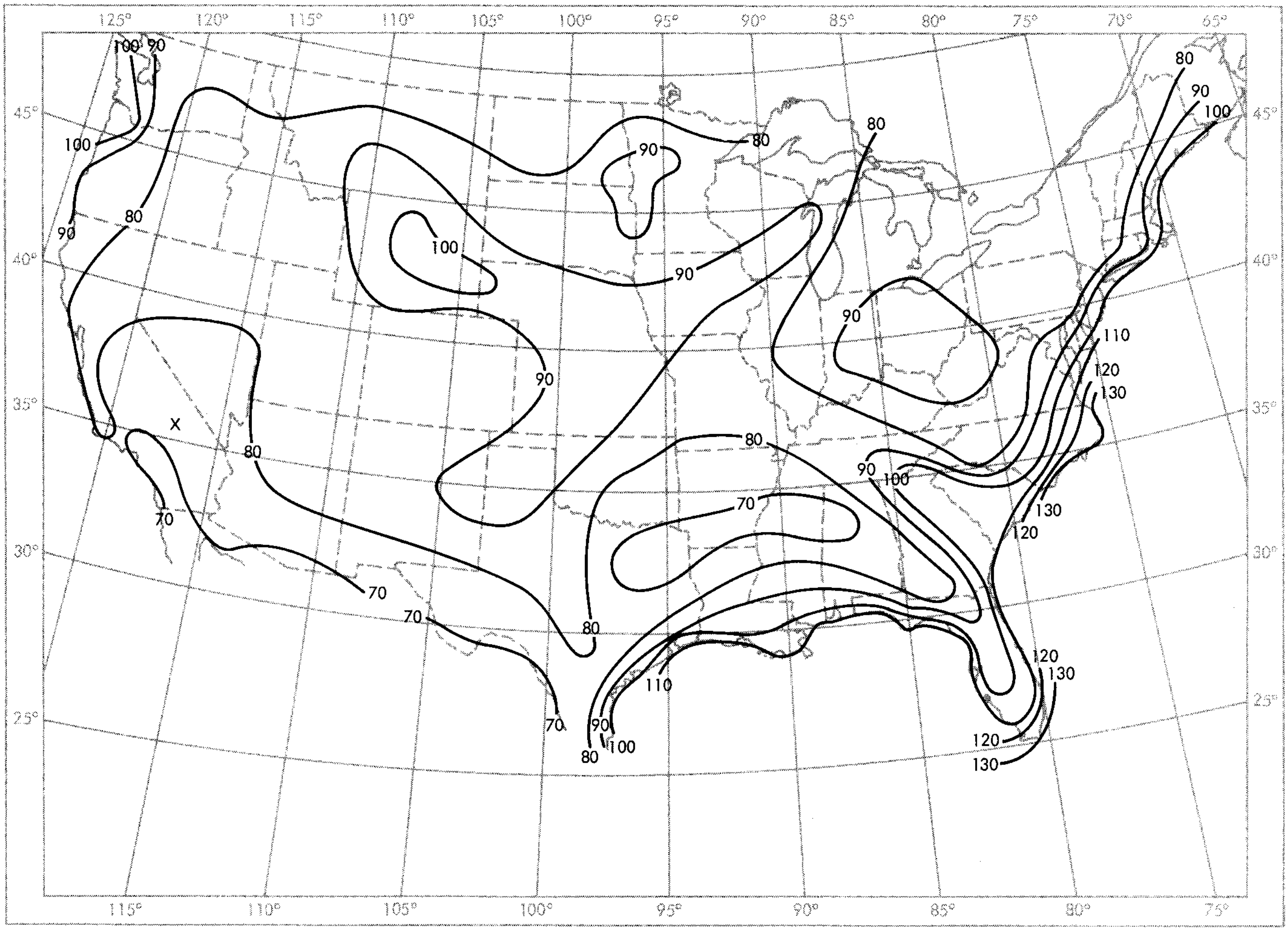

Fig. 1. Wind speed (mi/h): annual extreme-mile 30 ft above ground, 100-yr mean recurrence interval (from Ref. 4)

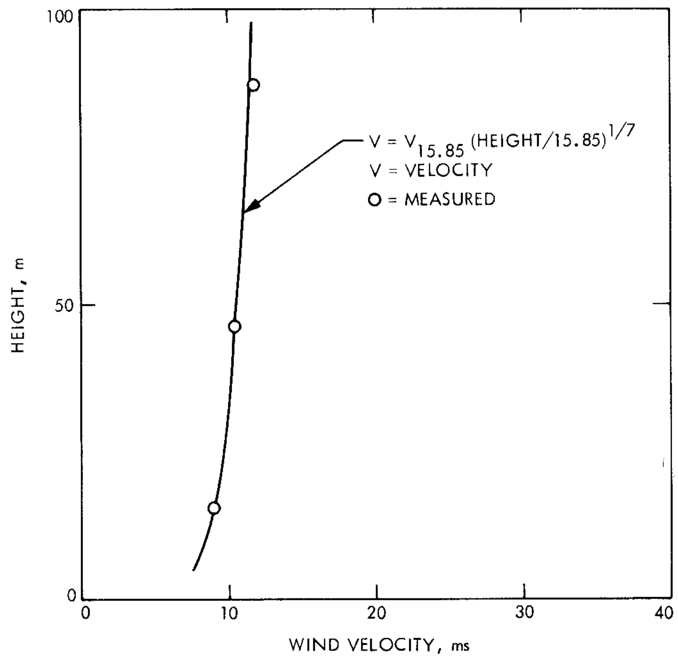

Fig. 2. Wind velocity vs height at Mars site

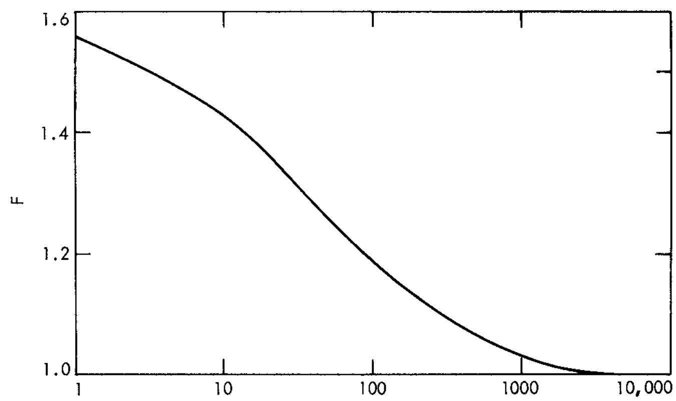

Fig. 3. Ratio F of probable maximum speed averaged over period t to that averaged over 1 hour (exposure C)